UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK
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EVE SILBERBERG; JENNIFER REBECCA WHITE; AND MICHAEL EMPORER,

Plaintiffs,

- against -

BOARD OF ELECTIONS OF THE STATE OF NEW YORK, et al.,

Defendants.

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AFFIRMATION OF STEPHEN C. GRAVES

16 CV 8336 (PKC)

STEPHEN C. GRAVES, declares, under penalty of perjury pursuant to 28 U.S.C. § 1746, that the following is true and correct:

1. I am the Abraham J. Siegel Professor of Management at the Massachusetts Institute of Technology, where I teach graduate and undergraduate subjects and do research in the fields of operations management, supply chain management and manufacturing systems.

2. I submit this declaration as my direct testimony for the trial in the within action and in support of the City Respondents' motion to dismiss/for summary judgment.

3. I have been an active member and participant in the Caltech/MIT Voting Technology Project since its initiation immediately after the 2000 election. My main contributions have been in terms of the operations of polling places and how these might be improved. With my graduate student Rong Yuan, I designed and implemented a software tool to aid in the design and planning of polling places, based on queuing theory. This tool uses queueing theory to calculate the minimal number of service stations at a process step in a polling place so as to satisfy a service target on maximum waiting times. A process step could be the act of voting, in which case the service stations correspond to voting machines or privacy booths.

This tool is posted on the Caltech/MIT Voting Technology Project web site, http://web.mit.edu/vtp/index.html.

4. I received A.B. and M.B.A. degrees from Dartmouth College in 1973 and 1974, respectively, and an M.S. and Ph.D. degrees from University of Rochester in 1976 and 1977, respectively.

5. I joined the MIT faculty in 1977 as an assistant professor, was promoted to associate professor with tenure in 1985, and then was promoted to full professor in 1987.

6. I served as the Deputy Dean of the MIT Sloan School of Management from September 1990 to August 1993. I served as the Interim Director of the Engineering Systems Division from September 2012 to December 2013. I was elected and served as the Chair of the MIT Faculty from July 2001 to June 2003.

7. I am a Fellow of INFORMS, the leading international association for professionals in operations research and analytics. I am a Fellow of the Manufacturing and Service Operations Management Society (MSOM), and a Fellow of the Production and Operations Management Society (POMS). MSOM and POMS are the two most prominent international organizations for academics in the field of operations management.

8. During my forty years at MIT, I have been responsible for a variety of subjects in operations management, supply chains and systems optimization and analysis. I have taught both elective and required subjects at the graduate level, mainly for students in professional masters programs. In addition I teach a project-based supply chain class for undergraduates.

9. In 2013 I was asked to make presentation before the Presidential Commission on Election Administration, on the topic of how queuing theory and concepts might help election officials improve the operations of polling places and reduce waiting times.

10. I have authored around 80 articles in peer-reviewed journals, 20 papers in refereed proceedings, and co-edited two handbooks on the methodology of operations management and supply chain management. *See* Exhibit A (C.V. of Stephen C. Graves).

11. I have conducted collaborative research projects with numerous companies, including AT&T, IBM, Monsanto, Eastman Kodak, Amazon.com, Intel, General Motors, Boeing, Teradyne, Staples. Samsung and Mitsubishi. The nature of this research entails the mathematical modeling and optimization of their systems for production and distribution.

12. I have been retained by the City of New York to provide expert testimony in this case. I am compensated for my time at the rate of $300 per hour.

INTRODUCTION TO ANALYSIS

13. I have been asked by the City of New York to provide analysis on the effect of allowing the taking of photographs in polling places on the waiting time at the polling site. By allowing the taking of photographs in polling places, I understand this to include taking photographs of one's ballot and one's image while in the polling place. I also understand it to include, but not be limited to, the taking of a "ballot selfie," which is a photograph of a voter's image that also includes the voter's marked ballot.

14. I have performed this analysis based on my knowledge of election administration in general and polling place practices in particular, which has been derived from my involvement in the Caltech/MIT Voting Technology Project since 2000.

15. As part of this project I consulted to Professor Charles Stewart, MIT, who wrote *Managing Polling Place Resources*,[1] which is a report that discusses the applicability of queuing theory to polling place practices, gives practical advice about how election officials might adapt those practices to their management of elections, and gives two case studies.

16. Based on my research and knowledge of polling place operations throughout the United States, it is clear that allowing photographs of voters and their ballots, including "ballot selfies," will affect at least two aspects of polling place operations. Allowing photographs will

17. Take time, and as such will increase the service time for a voter to complete one or more process steps within the polling place. The primary process steps are check in, vote and scan the ballot. If a voter were, say, to take a selfie while in the privacy booth, the amount of time for the voter to complete the task of completing the ballot will be extended by the time required to take the photograph.

18. And increase wait times to check in, vote, and scan ballots. If the time to complete a process step takes longer, then from a standard application of queueing concepts we would expect there will be more queueing and a longer average wait time experienced by the voters.

[1] http://web.mit.edu/vtp/Managing%20Polling%20Place%20Resources.pdf. The executive summary may be found at http://web.mit.edu/vtp/Managing%20Polling%20Place%20Resources%20executive%20summary.pdf.

LINES AT POLLING PLACES

19. The most immediate and direct consequence that lifting the ban on photographs in polling places will have on election administration will be to increase service times in polling places, which will ultimately create longer lines at the polls. There have long been concerns about long lines at the polls in American elections, but the concern reached a new height in 2012, when President Barack Obama made mention in his victory speech of supporters waiting a long time to vote.[2] President Obama followed up on this comment by appointing a bipartisan Presidential Commission on Election Administration (PCEA) in 2013. The PCEA was charged with studying (among other things) "the number, location, management, operation, and design of polling places" as well as "the training, recruitment, and number of poll workers…"[3]

20. The PCEA's main recommendation relating to long lines was that election officials should adopt techniques that have long been used in industrial engineering and management science to manage queues.[4] The PCEA's report also highlighted a website managed by the Caltech/MIT Voting Technology Project that hosts basic online tools that could be adapted by state and local officials to this purpose.[5]

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[2] CNN, "Transcript: Obama's victory speech," November 7, 2012, http://politicalticker.blogs.cnn.com/2012/11/07/transcript-obamas-victory-speech/.

[3] U.S. Presidential Commission on Election Administration, "The American voting experience: Report and recommendations of the Presidential Commission on Election Administration," p. 5, http://web.mit.edu/supportthevoter/www/files/2014/01/Amer-Voting-Exper-final-draft-01-09-14-508.pdf. [Hereinafter "PCEA Report"]

[4] Ibid., 38–44.

[5] The URL for the website is http://web.mit.edu/vtp/.

21. Finally, the PCEA recommended as a benchmark that "…as a general rule, no voter should have to wait more than half an hour in order to have an opportunity to vote."[6]

22. According to the discipline of queuing theory, the core to understanding how long customers — or voters, in the case of elections — will wait to be served in a system is to focus on three factors, or variables.[7] These variables are:

- Arrival rates: How rapidly do voters arrive to the polling place on a per-unit-time basis (*e.g.*, average arrivals per hour or minute)?
- Service times: How long does it take a voter to perform a relevant task related to voting (*e.g.*, average check-in time, in minutes)?
- Service stations: How many service locations are available to handle voter tasks (*e.g.*, poll books)?

23. One important complication in the application of queuing models to polling places is that most polling places possess more than one possible queue.[8] In New York City, for instance, it is possible for lines to form waiting (1) to check in, (2) to vote at a booth, and (3) to scan the ballot at a scanner.

24. From queuing theory we know that, holding everything else constant, voters will wait in longer lines on Election Day (1) the more voters come to the polls, (2) the longer it takes them to check in, vote, or scan ballots, and (3) the fewer poll books, privacy

[6] PCEA Report, 14.

[7] An introduction to queuing theory as applied to polling places may be found at Charles Stewart III, "Managing Polling Place Resources," Report of the Caltech/MIT Voting Technology Project, http://web.mit.edu/vtp/Managing%20Polling%20Place%20Resources.pdf.

[8] Stewart, "Managing Polling Place Resources," 17.

booths, and scanners there are in a precinct. What is less intuitive is that queuing systems like those in polling places are very fragile. Small changes in parameters, such as an increase in check-in times or ballot-marking times, even by a few seconds, can result in a polling place suffering from uncontrollable lines and voters waiting an unacceptably long time to vote.

THE APPLICATION OF QUEUING TO THE POLLING-PLACE PHOTOGRAPH ISSUE

25. One major effect that allowing photographs to be taken in polling places will have on polling place dynamics is that service times will increase. In this section, I present the analysis that I did to explore the potential impact on waiting times from an increase in the service time due to allowing photographs in the polling site.

26. From data that I received from New York City election officials, I selected ten polling sites as the basis for my study. I selected the sites that saw the most voters in the recent 2016 Presidential election. These are the sites that are likely to see the largest impact from an increase in service times due to photography. The list of sites is given in table 1. The first eight sites are in Manhattan, and the last two are in Queens.

Poll Site Name	ED Count	Total Ballot Count	Privacy Booths	ADA Privacy Booths
Frank McCourt HS	12	7540	28	2
HS of Art & Design	15	9620	36	2
PS 41	12	7536	27	2
PS 163	15	8387	32	2
Robert Wagner Middle School	15	8929	35	2
PS 165	14	7768	29	2
PS 33	16	8141	33	2
PS 290 (Manh New School)	14	9242	33	2
PS 85-Judge Charles Vallone	11	7558	30	2
PS 70-Queens	15	7458	29	2

Table 1: Polling sites

27. Each of these sites serves multiple Election Districts (EDs). The total ballot count is the total number of ballots across the entire set of EDs at the polling site.

28. At each site the EDs share a common set of privacy booths.

29. For this analysis I chose to consider the impact on waiting at the process step at which the voter marks the ballot, *i.e.*, the vote step. As such I do not consider the impact at check in or the impact at ballot scanning. This choice is based on a judgment that the prevalence for taking photographs will be greatest at the vote step: here the voter can capture an image of the marked ballot in the privacy of the privacy booth, possibly along with an image of the voter.

30. To analyze each polling site and the impact from photography, we will use a simulation. For the simulation, we need to specify the process and rate at which voters arrive to the polling station; the service time to vote and possibly to take a photograph; and the number of servers, which in this case is the number of privacy booths in which a voter can mark a ballot.

31. For the arrival process I chose to focus the simulation on the *morning surge*, namely the time window from 6 a.m. when the polls open until 10 a.m. The Board of Elections in the City of New York provided me with the following data:

- Number of votes cast by hour by borough at the November 2016 General Election
- Number of votes cast at each poll site at the November 2016 General Election
- Equipment, including number of privacy booths and scanners, used at each poll site at the November 2016 General Election.

32. This information revealed that the number of voters arriving in this time window was much higher than later in the day. For instance, for the polling sites in Manhattan, 40% of the voters that voted on Election Day came to the polls between 6 a.m. and 10 a.m. In Queens this percentage was slightly lower, namely 32%.

33. We focus the simulation on the morning surge, as this is where any waiting will be the greatest, due to this period having the highest arrival rate relative to other times of the day.

34. For the simulation we will assume that the voters will arrive according to a Poisson process. Effectively this assumption means that voters arrive randomly one at a time.

This is a common and widely accepted assumption for modeling service systems such as polling sites, call centers, and service counters.

35. The service time to vote consists of the total time from when the voter first occupies the booth until the next voter can occupy the booth (assuming there is a next voter in queue). Hence, the service time includes not only the time to mark the ballot, but also the time for the voter to exit the booth and for the next voter to enter the booth.

36. For this analysis, I assume that the service time to vote will be three minutes. That is, it will take three minutes between the time when a voter first arrives at the booth and the time when the next voter can occupy the booth. To my knowledge there were no measurements of the time to vote in New York City from the last election, so my assumption is an educated estimate. In partial support of this assumption, I make two observations. First, Professor Charles Stewart made measurements of time to vote in Michigan for the 2016 Presidential Election and found that thea titme tovote to be slightly more than six minutes.[9] Second, I note that if the average time tovote in New York City were three minutes, then the utilization of the privacy booths at the ten polling sites on the recent Election Day would have been between 0.78 and 0.88, as shown in Table 2. The booth utilization[10] represents the percent of time that each booth is expected to be occupied over the 15-hour election day. An 80% to

[9] Expert testimony of Prof. Charles Stewart for case of JOEL CROOKSTON, Plaintiff, v RUTH JOHNSON, Michigan Secretary of State, No. 1:16-cv-01109.

[10] Utilization is calculated as the number of voters divided by the capacity; the capacity represents how many voters could be processed in 15 hours given the number of privacy booths. If the time to vote is 3 minutes, then each booth can process 20 voters per hour or 300 voters over the Election Day (15 hours). Then the capacity for a polling site is the number of booths, including BMDs and ADA booths, multiplied by 300 voters per day.

85% utilization seems fairly reasonable, as it indicates that there was sufficient capacity over the day to handle the number of voters that came to vote.

Poll Site Name	Total Ballot Count	Privacy Booths	ADA Privacy Booths	Booth Utilization
Frank McCourt HS	7540	28	2	0.84
HS of Art & Design	9620	36	2	0.84
PS 41	7536	27	2	0.87
PS 163	8387	32	2	0.82
Robert Wagner Middle School	8929	35	2	0.80
PS 165	7768	29	2	0.84
PS 33	8141	33	2	0.78
PS 290 (Manh New School)	9242	33	2	0.88
PS 85-Judge Charles Vallone	7558	30	2	0.77
PS 70-Queens	7458	29	2	0.80

Table 2: Booth utilization

37. For the simulation I assume that the time to vote is exactly three minutes for each voter. This is a simplification as there is much variability from voter to voter. By assuming that the time to vote is a constant, I am under-estimating the variability in the system, which will result in an under-estimation of the extent of waiting.

38. We also need an estimate of the time to take a photograph while voting. I assume that is 18 seconds, based on measurements made by Professor Charles Stewart for the State of Michigan.[11]

39. We need an estimate of the percentage of voters that will take a photograph while voting. For the simulation, I use three possibilities, namely 20%, 50% and 100%. I am not aware of any data for informing this choice; hence, I consider a range of possibilities.

40. For each photography specification, I set the time to vote to equal nominal time to complete the ballot (three minutes), plus the expected time for taking a photograph (the percent of photograph takers * 18 seconds). For instance, for the 50% case, the time to vote = 3 minutes + .5*18 seconds = 3.15 minutes.

41. For the simulation we also need to set the number of privacy booths at each polling site. Here I set this to equal to the number of general privacy booths plus the ADA privacy booths. The ADA booths are just wider and lower compared to the general privacy booths and can be used by anyone.

42. The simulation is designed to simulate the arrival of voters over the surge period, from 6 a.m. to 10 a.m.. For each run of the simulation I simulate a fixed number of arrivals that corresponds to the expected number of voters in this time window. I assume that no voter arrives before the polls open. The actual arrival time of each voter is randomly generated, starting at 6 AM. An overview of the logic of the simulation is as follows:

a) Arrival times are generated for each voter

[11] Expert testimony of Prof. Charles Stewart for case of JOEL CROOKSTON, Plaintiff, v RUTH JOHNSON, Michigan Secretary of State, No. 1:16-cv-01109.

b) At the arrival time, the voter will occupy a vacant booth if one is available; if not, the voter joins a queue and will wait until a booth becomes available.

c) Once in the booth, a voter will occupy the booth for the time it takes to vote (three minutes), plus any additional time if the voter takes a photograph.

d) The voter's wait time is computed as the difference between the time that the voter first occupies a booth and the arrival time for the voter.

43. For each polling site, we repeat the simulation ten times so as to simulate ten different randomly generated arrival patterns. We then average the results, where we compute the average waiting time, the maximum waiting time, and the percent of voters that would be required to wait for more than 30 minutes.

44. The results of the simulations for the ten sites are given in Table 3 (average wait times), Table 4 (maximum wait time), and Table 5 (Percent of voters with wait more than 30 minutes). In each table I report the measure for the case of no photography, and then for the cases in which 20%, 50% and 100% of the voters take a photograph.

Poll Site Name	no photographs	20%	50%	100%
Frank McCourt HS	30.04	33.03	37.50	44.96
HS of Art & Design	31.15	34.16	38.67	46.19
PS 41	35.25	38.34	42.97	50.69
PS 163	37.40	30.31	34.69	41.99
Robert Wagner Middle School	22.86	25.72	30.00	37.16
PS 165	30.20	33.18	37.64	45.08
PS 33	18.28	21.02	25.14	32.04
PS 290 (Manh New School)	38.18	41.31	46.02	53.87
PS 85-Judge Charles Vallone	0.50	0.74	1.76	5.61
PS 70-Queens	0.91	1.56	3.17	7.60

Table 3: Average Wait Time (minutes)

Poll Site Name	no photographs	20%	50%	100%
Frank McCourt HS	61.34	67.33	76.31	91.31
HS of Art & Design	63.91	69.96	79.05	94.18
PS 41	71.60	77.78	87.05	102.50
PS 163	56.51	62.36	71.16	85.52
Robert Wagner Middle School	46.70	52.45	61.07	75.46
PS 165	61.28	67.27	76.25	91.23
PS 33	37.60	43.16	51.50	65.42
PS 290 (Manh New School)	77.57	83.86	93.31	109.96
PS 85-Judge Charles Vallone	2.52	3.16	4.93	11.94
PS 70-Queens	3.25	4.60	7.90	16.76

Table 4: Maximum Wait Time (minutes)

Poll Site Name	no photographs	20%	50%	100%
Frank McCourt HS	49%	54%	59%	66%
HS of Art & Design	50%	55%	61%	67%
PS 41	57%	61%	65%	70%
PS 163	45%	50%	57%	64%
Robert Wagner Middle School	37%	43%	51%	60%
PS 165	49%	53%	59%	66%
PS 33	20%	31%	41%	52%
PS 290 (Manh New School)	60%	64%	68%	72%
PS 85-Judge Charles Vallone	0%	0%	0%	0%
PS 70-Queens	0%	0%	0%	0%

Table 5: Percentage of voters that wait more than 30 minutes

45. From the simulation, we find that there is substantial waiting at several of the polling sites during the morning surge, even without any photography. For instance, consider PS 165. The average wait for a voter in the morning surge is 30 minutes, the maximum wait is 61 minutes, and 49% of the voters will wait more than 30 minutes. This is attributable to the a fact that the arrival rate exceeds the capacity at the privacy booths during this time window, and the queue awaiting the privacy booths will slowly grow over the four hour period. After the surge, when the arrival rate drops the site will catch up and will clear the queue as the day goes on.

46. Frank McCourt, the HS of Art & Design, PS 41, Robert Wagner, PS 33, PS,163 and PS 290 exhibit similar performance as does PS 165, with no photography. The other two sites (PS 85, PS 70), though, are more lightly loaded and have minimal waiting in the morning surge, when there is no photography.

47. When we allow photographs, the tables show the impact. This impact is greatest on the first eight sites, which are in Manhattan. For instance, consider Frank McCourt

HS. The average wait increases by three minutes if 20% of voters take photographs, by seven minutes if 50%, and by fifteen minutes if all voters take a photograph. Similarly the maximum wait time goes from 61 minutes to 67 minutes (20% take photographs), to 76 minutes (50%) and to 91 minutes (100%). Finally, the percent of voters with 30 minute or more waits increases from 49% to 54% (20% taking photographs), to 59% (50% taking photographs) and to 64% (100% taking photographs).

48. From this simulation we observe that there can be a quite dramatic increase in wait times during the morning surge, depending upon the percent of voters taking photographs. This is particularly pronounced at the busiest polling sites in Manhattan which experience the greatest morning surge.

49. As noted above, we chose a service time to vote of three minutes. A natural question is how sensitive are the results to this choice of service time. I reran the analysis for a single polling site for a range of possible service times. I chose the Frank McCourt HS as the site, and redid the analysis with service time set to 2.5 minutes, 3.5 minutes, 4 minutes and 4.5 minutes. The results are shown in the following tables.

50. From these tables we first observe that the wait time is quite sensitive to the assumed service or vote time. When the vote time is 2.5 minutes, there is modest queueing. However, when the vote time is 3 minutes, there is significant queuing, with 49% of the voters waiting more than 30 minutes for the case of no photographs. As we increase the vote time, the extent of queuing increases: the average wait time approaches 105 minutes when the vote time is 4.5 minutes, compared to ‘only’ 30 minutes when the vote time is 3 minutes and seven minutes when the vote time is 2.5 minutes.

51. Second we observe that allowing photographs will further increase the wait time in all scenarios. For instance, when vote time is 2.5 minutes, the average wait time would increase from seven minutes to over 21 minutes if photographs are allowed and everyone takes a photo; and the maximum wait time grows from 14 minutes to 44 minutes. If the vote time is larger, say 4 minutes, the average wait time increases by nearly 15 minutes (from 80 minutes to 95 minutes) and the maximum wait time increases by 30 minutes, if everyone takes a photograph.

vote time	no photographs	20%	50%	100%
2.5	7.05	9.92	14.35	21.78
3	30.04	33.03	37.50	44.96
3.5	54.94	57.92	62.40	69.87
4	79.61	82.59	87.07	94.54
4.5	104.96	107.95	112.43	119.89

Table 6: Average wait time at Frank McCourt HS, as it depends on vote time

vote time	no photographs	20%	50%	100%
2.5	14.25	19.99	28.87	43.72
3	61.34	67.33	76.31	91.31
3.5	110.48	116.48	125.48	140.48
4	160.89	166.89	175.89	190.89
4.5	212.17	218.17	227.17	242.17

Table 7: Maximum wait time at Frank McCourt HS, as it depends on vote time

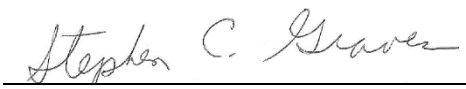
vote time	no photographs	20%	50%	100%
2.5	0%	0%	3%	31%
3	49%	54%	59%	66%
3.5	73%	74%	76%	78%
4	81%	81%	82%	84%
4.5	85%	85%	86%	87%

Table 8: Percent waiting more than 30 minutes at Frank McCourt HS, as it depends on vote time

52. It is worth noting that some ballots contain referenda questions. Those ballots, which can be text heavy, are likely to result in longer service times, which will result in extended wait times.

53. This analysis has just considered the impact at the queue leading to the privacy booths. Waiting can also occur at check in and at ballot scanning. A similar analysis could be done for these process steps. Again depending upon one's assumptions about photography at these steps, we expect there will be increased waiting there, too.

Dated: New York, New York
July 28, 2017



STEPHEN C. GRAVES

EXHIBIT A

December 2016

CURRICULUM VITAE

Name: Stephen C. Graves
Department: Sloan School of Management
Date of Birth: November 1951
Place of Birth: Pittsfield, MA
Citizenship: U.S.
Marital Status: Married

Education:

School	Degree	Date
Dartmouth College	A.B.	1973
Dartmouth College	M.B.A.	1974
University of Rochester	M.S.	1976
University of Rochester	Ph.D.	1977

Title of Doctoral Thesis: "The Multiproduct Production Cycling Problem for Stochastic Demand and Finite Production Capacity"

Principal Fields of Interest: Operations Management, Applied Operations Research

Name and Rank of Other SSM Faculty in Same Field:

Gabriel R. Bitran	Professor
Steven D. Eppinger	Professor
Vivek Farias	Associate Professor
Charles H. Fine	Professor
Jonas Jonasson	Assistant Professor
Retsef Levi	Professor
Georgia Perakis	Professor
Donald B. Rosenfield	Senior Lecturer
Zeynep Ton	Adjunct Professor
Nikolaos (Nikos) Trichakis	Assistant Professor
Tauhid Zaman	Assistant Professor
Yanchong Karen Zheng	Assistant Professor

Non-M.I.T. Experience:

Employer	Position	Date
Educational Testing Service	Management Science Analyst	Summer 1972
Simonds Saw and Steel	Management Science Analyst	Summer 1973
University of Rochester	Research Assistant	Summer 1974
University of Rochester	Instructor	Summers 75-77
University of Rochester	Visiting Research Associate	Summers 79-80
Eastman Kodak	Management Science Analyst	Summers 80-81
Shanghai Institute of Mechanical Engineering	Visiting Professor	July 82-Jan 83
Optiant	Member of Advisory Board	2000 - 2009
Servigistics	Chief Scientist	2001 – 2004
JDA	Chief Science Advisor	2005 - 2011

History of M.I.T. Appointments:

Rank	Beginning	Ending
Assistant Professor, Sloan School of Management	7/77	6/81
Associate Professor, Sloan School of Management	7/81	6/87
Professor, Sloan School of Management	7/87	
Leaders for Manufacturing Professor	7/88	6/93
Deputy Dean	9/90	8/93
Abraham J. Siegel Professor of Management	10/95	
Professor, Engineering Systems Division (joint)	7/99	6/15
Professor, Mechanical Engineering Department (joint)	7/05	
Interim Director, Engineering Systems Division	9/12	12/13

Industrial Consulting Record:

Firm and Dates

Bausch and Lomb, 1976; Shycon Associates, 1980 - 1986; GTE Research Laboratories, 1981 - 1982, 1984, 1986; Illinois Central Gulf Railroad, 1982; C.S. Draper Laboratory, 1982 - 1984; ROLM Corporation, 1984, 1993; Palladian Software, 1986; GM Research Laboratories, 1986 – 1997, 2003 - 2004; W.R. Grace, 1987, 1991; Millipore, 1988; WearGuard, 1988; Alcoa, 1993 – 1994; Amazon.Com, 2001; Invistics, 2002 – 2005; Servigistics, 2001 – 2003; JDA, 2003 – 2011; Honeywell, 2003; FormFactor 2006; McMaster-Carr 2007; Sears Holdings, 2015.

Institute Activities:

Staff Member of Operations Research Center, 1977 - 2017
Undergraduate Advisor, 1978 - 2017
Freshman Advisor, 1991- 1998, 2002 - 2005, 2008 - 2017
Member of Sloan Program Committees: 1978 – 2013 (SB); 1978-1980 (SM); 1985-1987, 1994 – 1998, 2005 - 2008 (PhD).
Chair of Sloan Undergraduate Education Committee, 2010 - 2013
Member of Committee on Academic Performance, 1984-1986
Member of Committee on Discipline, 1995 – 1997
Chair of Committee on Discipline, 1997 – 2001
Member of Sloan Dean Search Committee, 1987
Member of Freshman Housing Committee, 1989
Acting CoDirector, Leaders for Manufacturing Program, 1989-1990
Chair of Parking and Transportation Committee, 1989-1995
Member of Parking and Transportation Committee, 2016 - 2017
CoDirector, Leaders for Manufacturing Program, 1994 - 2001
CoDirector, System Design and Management Program, 1999 - 2001
Chair of Task Force on ROTC, 1995 – 1996
Chair of Sloan Dean Search Committee, 1998
Chair of MIT Faculty, 2001 – 2003
Chair of Faculty Policy Committee, 2001 – 2003
Member of Task Force on Campus Security, 2001
Member, ad hoc committee on Access to and Disclosure of Scientific Information, 2002
Chair, review committee on Faculty Newsletter, 2002

Faculty Newsletter, Editorial Board, 2003 – 2009
Member of Faculty Advisory Committee for MIT Presidential Search, 2004 - 2005
Member of Committee on Undergraduate Admissions and Financial Aid, 2004 – 2006
Chair of Committee on Undergraduate Admissions and Financial Aid, 2007 – 2008
Member of ad hoc committee on MIT Disciplinary System, 2005
Member of ad hoc committee on MLK Visiting Professor Program, 2006
Member of Stellar faculty advisory committee, 2004 – 2010
Chair of Search Committee for Dean of Graduate Student Office, 2007
Chair of Dean for Graduate Education Search Advisory Committee, 2010
Chair of Committee on Graduate Policy, 2008 – 2011
Member of Commencement Committee, 2007 – 2011
Member of Search Committee for Director of Student Financial Services, 2008- 2009
Chair of Search Committee for Director of Financial Aid, 2009 – 2010
Member of MIT150 Steering Committee, 2008 – 2011
Chair of ad hoc committee: Strategic Review of MIT Sloan's Undergraduate Programs, 2009
Member of Education Working Group of the MIT Planning Task Force, 2009
Member of NGS3 faculty advisory group, 2009- 2011
Member of Independent Activities Period (IAP) Subcommittee of the FPC, 2012
Member of Committee on the Undergraduate Program, 2011 – 2013
Chair of Committee on the Undergraduate Program, 2013 - 2014
Co-chair of Task Force for Graduate Student Professional Development, 2012 – 2013
Member of ROTC Oversight Committee, 2012-2014
Member of Employee Assistance Program (EAP) Advisory Committee, 2015 - 2017
Member of Ad Hoc Group on the Future of Libraries, 2015 – 2016
Member of Committee on Campus Planning, 2016 - 2017
Member of Committee on Community Giving, 2016 - 2017

Professional Activities:

Associate Editor - *Operations Research*, 1981-1986; *Management Science*, 1983-1986, 2001 - 2003; *Manufacturing & Service Operations Management*, 1997 – 2008, 2015 - 2017
Department Editor - *Management Science*, 1987-1991
Area Editor – *Operations Research*, 2006 – 2008
Editor - *Manufacturing & Service Operations Management*, 2009 - 2014
Functional Area Editor - *Interfaces*, 1985-1986
Editor, Edelman Special Issue, *Interfaces*, 1989 - 2007
Member - INFORMS
Member of Student Affairs Committee for ORSA, 1980-1983
Edelman Award Committee, 1988 – 2007; 2011- 2012 (Chair)
INFORMS (formerly TIMS/ORSA) Publication Committee, 1990-1998, 2006 - 2008
Vice President, Publications - INFORMS, 1994 – 1995

Awards:

Fellow of the Manufacturing and Service Operations Management Society
Fellow of the Production and Operations Management Society
INFORMS Fellow
1999 Billard Award for service at MIT

2012 MSOM Distinguished Service Award
Zaragoza Logistics Center: Medal of Distinction (2013)

Subjects Taught:

15.062	Decision Models for Management
15.761	Operations Management
15.763	Practice of Operations Management
15.764	Theory of Operations Management
15.053	Introduction to Management Science
15.770J	Transportation and Logistics Analysis
15.066J	System Optimization and Analysis for Manufacturing
15.762	Operations Management: Models and Applications
15.762J	Supply Chain Planning
15.763J	Manufacturing Systems and Supply Chain Design
15.A03	Operations Research Can be Fun (freshmen seminar)
EC.733J	D Lab Supply Chains (15.772J)

Publications**:**

Papers

1. "Optimal Storage Assignment in Automatic Warehousing Systems," (with W.H. Hausman and L.B. Schwarz), *Management Science*, February 1976, Vol. 22, 629-638.

2. "Single Cycle Continuous Review Policies for Arborescent Production/Inventory Systems," (with L.B. Schwarz), *Management Science*, January 1977, Vol. 23, 529-540.

3. "Storage-Retrieval Interleaving in Automatic Warehousing Systems." (with W.H. Hausman and L.B. Schwarz), *Management Science*, May 1977, Vol. 23, 935-945.

4. "A Note on 'Critical Ratio Scheduling: An Experimental Analysis'," *Management Science*, August 1977, Vol. 23, 1358-1359.

5. "On 'Production Runs for Multiple Products: The Two-Product Heuristic'," (with R.W. Haessler), *Management Science*, July 1978, Vol. 24, 1194-1196.

6. "Scheduling Policies for Automatic Warehousing Systems: Simulation Results," (with W.H. Hausman and L.B. Schwarz), *AIIE Transactions*, September 1978, Vol. 10, 260-270.

7. "A Note on the Deterministic Demand Multi-Product Single-Machine Lot Scheduling Problem," *Management Science*, March 1979, Vol. 25, 276-280.

8. "A Methodology for Studying the Dynamics of Extended Logistics Systems," (with J. Keilson), *Naval Research Logistics Quarterly*, July 1979, Vol. 26, 169-197.

9. "An n-Constraint Formulation of the (Time Dependent) Traveling Salesman Problem," (with K.R. Fox and B. Gavish), *Operations Research*, July-August 1980, Vol. 28, 1018-1021.

10. "The Multi-Product Production Cycling Problem," *AIIE Transactions*, September 1980, Vol. 12, 233-240.

11. "A One-Product Production/Inventory Problem with Continuous Review Policy," (with B. Gavish), *Operations Research*, September-October 1980, Vol. 28, 1228-1236.

12. "Production/Inventory Systems with a Stochastic Production Rate Under a Continuous Review Policy," (with B. Gavish), *Computers and Operations Research*, 1981, Vol. 8, 169-183.

13. "Multistage Lot-Sizing: An Iterative Procedure," in TIMS Studies in Management Science, *Multi-Level Production/Inventory Systems: Theory and Practice*, edited by L.B. Schwarz, 1981, Vol. 16, 95-109.

14. "The Compensation Method Applied to a One-Product Production Inventory Model," (with J. Keilson), *Mathematics of Operations Research*, May 1981, Vol. 6, 246-262.

15. "A Review of Production Scheduling," *Operations Research*, July-August 1981, Vol. 29, 646-675.

16. "Problem Formulations and Numerical Analysis in Integer Programming and Combinatorial Optimization," (with J.F. Shapiro), in *Mathematical Programming with Data Perturbations I*, edited by A.V. Fiacco, 1982, 131-148.

17. "Using Lagrangean Techniques to Solve Hierarchical Production Planning Problems," *Management Science*, March 1982, Vol. 28, 260-275.

18. "The Application of Queueing Theory to Continuous Perishable Inventory Systems," *Management Science*, April 1982, Vol. 28, 400-406.

19. "A Multiple-Item Inventory Model with a Job Completion Criterion," *Management Science*, November 1982, Vol. 28, 1134-1137.

20. "System Balance for Extended Logistic Systems," (with J. Keilson), *Operations Research*, March-April 1983, Vol. 31, 234-252.

21. "An Integer Programming Procedure for Assembly System Design Problem," (with B. Lamar), *Operations Research*, May-June 1983, Vol. 31, 522-545.

22. "Scheduling of Re-entrant Flow Shops," (with H.C. Meal, D. Stefek, and A.H. Zeghmi), *Journal of Operations Management*, August 1983, Vol. 3, 197-207.

23. "A Simple Stochastic Model for Facility Planning in a Mental Health Care System," (with H.S. Leff, J. Natkins, and M. Senger), *Interfaces*, October 1983, Vol. 13, 101-110.

24. "Deep-Draft Dredging of U.S. Coal Ports: A Cost-Benefit Analysis," (with M. Horwitch and E.H. Bowman), *Policy Sciences*, Vol. 17, 1984.

25. "A Study of Production Smoothing in a Job Shop Environment," (with A.B. Cruickshanks and R.D. Drescher), *Management Science*, March 1984, Vol. 30, 368-380.

26. "A Minimum Concave-Cost Dynamic Network Flow Problem with an Application to Lot-Sizing," (with J.B. Orlin), *Networks*, Vol. 15, 1985.

27. "Description and Field Test of a Mental Health System Resource Allocation Model," (with H.S. Leff, J. Natkins, and J. Bryan), *Administration in Mental Health*, Fall 1985, Vol. 13, 43-68.

28. "Continuous-Review Policies for a Multi-Echelon Inventory Problem with Stochastic Demand," (with M. DeBodt), *Management Science*, October 1985, Vol. 31, 1286-1299.

29. "A Multi-Echelon Inventory Model for a Repairable Item with One-for-One Replenishment," *Management Science*, October 1985, Vol. 31, 1247-1256.

30. "An LP Planning Model for a Mental Health Community Support System," (with H.S. Leff and M. Dada), *Management Science*, February 1986, Vol. 32, 139-155.

31. "Overlapping Operations in Material Requirements Planning," (with M.M. Kostreva) *Journal of Operations Management*, Vol. 6, No. 3, May 1986, 283-294.

32. "Two-Stage Production Planning in a Dynamic Environment," (with H.C. Meal, S. Dasu, Y. Qiu), in Lecture Notes in Economics and Mathematical Systems, *Multi-Stage Production Planning and Inventory Control*, edited by S. Axsater, Ch. Schneeweiss, and E. Silver, Springer-Verlag, Berlin, 1986, Vol. 266, 9-43.

33. "A Tactical Planning Model for a Job Shop," *Operations Research*, July-August 1986, Vol. 34, 522-533.

34. "Equipment Selection and Task Assignment for Multiproduct Assembly System Design," (with C.A. Holmes Redfield) *International Journal of Flexible Manufacturing Systems*, 1988, Vol. 1, No. 1, pp. 31-50.

35. "Safety Stocks in Manufacturing Systems," *Journal of Manufacturing and Operations Management*, 1988, Vol. 1, No. 1, pp. 67-101.

36. "Determining the Spares and Staffing Level for a Repair Depot," *Journal of Manufacturing and Operations Management*, 1988, Vol. 1, No. 2, pp. 227-241.

37. "A Composite Algorithm for the Concave-Cost Network Flow Problem," (with A. Balakrishnan) *Networks*, Vol. 19, 1989, pp. 175-202.

38. "A Tactical Planning Model for Manufacturing Subcomponents of Mainframe Computers," (with C. Fine), *Journal of Manufacturing and Operations Management*, 1989, Vol. 2, No. 1, pp. 4-34.

39. "A Model for the Configuration of Incoming WATS Lines," (with R. H. Blake and P. C. Santos), *Queueing Systems*, 1990, Vol. 7, No. 1, pp. 3-21.

40. Handbook in Operations Research and Management Science, Volume 4: Logistics of Production and Inventory, edited by S. C. Graves, A. H. G. Rinnooy Kan and P. H. Zipkin, North-Holland, Amsterdam, 1993.

41. "Principles on the Benefits of Manufacturing Process Flexibility," (with W. C. Jordan), *Management Science*, April 1995, Vol. 41, No. 4, pp. 577 - 594.

42. "A Multi-Echelon Inventory Model with Fixed Replenishment Intervals," *Management Science*, January 1996, Vol. 42, No. 1, pp. 1-18.

43. "Cyclic Scheduling in a Stochastic Environment," (with H. Zhang), *Operations Research*, November-December 1997, Vol. 45, No. 6, pp. 894-903.

44. "A Dynamic Model for Requirements Planning with Application to Supply Chain Optimization," (with D. B. Kletter and W. B. Hetzel) *Operations Research*, May-June 1998, Vol. 46, Supp. No. 3, pp. S35-S49.

45. "OMAC: A System for Operations Modeling and Analysis," (with K. N. McKay and D. B. Kletter), *Annals of OR*, Vol. 72, 1997, pp. 241-264.

46. "Reducing Flow Time in Aircraft Manufacturing," (with Jackson Chao), *Production and Operations Management*, Spring 1998, Vol. 7, No. 1, pp. 38-52.

47. "A Single-Item Inventory Model for a Non-Stationary Demand Process," *Manufacturing & Service Operations Management*, 1999, Vol. 1, No. 1, pp. 50-61.

48. "Optimizing Strategic Safety Stock Placement in Supply Chains," (with S. P. Willems), *Manufacturing & Service Operations Management*, 2000, Vol. 2, No. 1, pp. 68 – 83.

49. "Manufacturing Planning and Control," in Handbook of Applied Optimization, edited by P. Pardalos and M. Resende, Oxford University Press, New York, 2002, pp. 728 - 746.

50. "Technology Portfolio Management: Optimizing Interdependent Projects over Multiple Time Periods," (with M. Dickinson and A. Thornton), *IEEE Transactions on Engineering Management*, Vol. 48, No. 4, November 2001, pp. 518-527.

51. "Creating an Inventory Hedge for Markov-Modulated Poisson Demand: Application and Model," (with H. S. Abhyankar), *Manufacturing & Service Operations Management*, Fall 2001, Vol. 3, No. 4, pp. 306 - 320.

52. "Process Flexibility in Supply Chains," (with B. T. Tomlin), *Management Science*, July 2003, Volume 49, Number 7, pp.907 - 919.

53. Handbook in Operations Research and Management Science, Volume 11: Supply Chain Management: Design, Coordination and Operation, edited by A. G. De Kok and S. C. Graves, Elsevier, Amsterdam, 2003.

54. "Supply Chain Design: Safety Stock Placement and Supply Chain Configuration," (with S. Willems), Chapter 3 in Handbook in Operations Research and Management Science, Volume

11: Supply Chain Management: Design, Coordination and Operation,, edited by A. G. De Kok and S. C. Graves, Elsevier, Amsterdam, 2003, pp. 95 - 132.

55. "Optimizing the Supply-Chain Configuration for New Products," (with S. Willems), *Management Science*, August 2005, Vol. 51, No. 8, pp. 1165 – 1180.

56. "Logistics Network Design with Supplier Consolidation Hubs and Multiple Shipment Options," (with M.L.F. Cheong, R. Bhatnagar), *Journal of Industrial and Management Optimization*, Volume 3, Number 1, February 2007, pp. 51–69.

57. "A Single-Product Inventory Model for Multiple Demand Classes," (with H. Arslan, T. Roemer) *Management Science*, September 2007, Vol. 53, No. 9, pp. 1486 – 1500.

58. "Flexibility Principles," Chapter 3 in Building Intuition: Insights from Basic Operations Management Models and Principles, edited by D. Chhajed and T. J. Lowe, Springer Science+Business Media, LLC, New York, 2008, pp. 33 – 49.

59. "Little's Law," (with J. D. C. Little), Chapter 5 in Building Intuition: Insights from Basic Operations Management Models and Principles, edited by D. Chhajed and T. J. Lowe, Springer Science+Business Media, LLC, New York, 2008, pp. 81 – 100.

60. "Strategic Inventory Placement in Supply Chains: Non-Stationary Demand," (with S. Willems) *Manufacturing & Service Operations Management*, Spring 2008, Vol. 10, No. 2, pp. 278 – 287.

61. "The Benefits of Re-Evaluating Real-Time Order Fulfillment Decisions," (with P. Xu and R. Allgor), *Manufacturing & Service Operations Management*, Spring 2009, Vol. 11, No. 2, pp 340-355.

62. "Strategic Safety Stocks in Supply Chains with Evolving Forecasts," (with Tor Schoenmeyr) *Manufacturing & Service Operations Management*, Fall 2009, Vol. 11, No. 4, pp 657-673.

63. "Optimal Planning Quantities for Product Transition," (with Hongmin Li and Donald Rosenfield), *Production and Operations Management*, March-April 2010, Vol. 19, No. 2, pp 142 – 155.

64. "Uncertainty and Production Planning," in Production and Inventories in the Extended Enterprise , edited by Karl G. Kempf, Pınar Keskinocak, and Reha Uzsoy, International Series in Operations Research & Management Science Volume 151, Springer US, 2011, pp 83 – 101.

65. "Setting Planned Lead Times for a Make-To-Order Production System under Master Schedule Smoothing," (with C. C. Teo and R. Bhatnagar), *IIE Transaction*, 2011, Vol. 43, No. 6, pp. 399-414.

66. "How to Catch a Tiger: Understanding Putting Performance on the PGA Tour," (with Douglas Fearing and Jason Acimovic), *Journal of Quantitative Analysis in Sports*, 2011, Vol. 7: Issue 1, Article 5. DOI: 10.2202/1559-0410.1268. Available at: http://www.bepress.com/jqas/vol7/iss1/5

67. “Pricing Decisions during Inter-generational Product Transitions,” (with Hongmin Li) *Production and Operations Management*, January-February 2012, Vol. 21, No. 1, pp 14-28.

68. "Remanufacturing and Energy Savings," (with T. Gutowski, S. Sahni, and A. Boustani), *Environmental Science & Technology*, 2011, Vol. 45, pp. 4540-4547.

69. “An Application of Master Schedule Smoothing and Planned Lead Time Control,” (with C. C. Teo and R. Bhatnagar), *Production and Operations Management*, March-April 2012, Vol. 21, No. 2, pp 211 - 223.

70. “Ship-Pack Optimization in a Two-Echelon Distribution System,” (with Naijun Wen and Justin Ren), *European Journal of Operational Research*, August 2012, Vol. 220, Issue 3, pp. 777- 785.

71. "Optimal Capacity Conversion for Product Transitions under High Service Requirements," (with Hongmin Li and Woonghee Tim Huh), *Manufacturing & Service Operations Management*, Winter 2014, Vol. 16, No. 1, pp. 46-60.

72. "A Forecast-driven Tactical Planning Model for a Serial Manufacturing Systems," (with Pallav Chhaochhria) *International Journal of Production Research*., December 2013, 51:23-24, pp. 6860-6879.

73. “Water Desalination Supply Chain Modeling and Optimization: The Case of Saudi Arabia,” (with Malak T. Al-Nory) *IDA Journal of Desalination and Water Reuse*, Vol. 5, No. 2 (2013) pp 64 - 74.

74. “Supply chain design for the global expansion of manufacturing capacity in emerging markets,” (with Stefan Weiler, Dayán Páez, Jung-Hoon Chun, Gisela Lanza), *CIRP Journal of Manufacturing Science and Technology*, Vol. 4, No. 3 (265-280), 2011.

75. "A network flow approach for tactical resource planning in outpatient clinics." (with Thu Ba T. Nguyen, Appa Iyer Sivakumar), *Health Care Management Science*, Vol. 18, No. 2 (2015): pp.124-136.

76. "Desalination supply chain decision analysis and optimization." (with Malak T. Al-Nory, Alexander Brodsky, Burçin Bozkaya), *Desalination* Vol. 347 (2014), pp. 144-157.

77. "Making Better Fulfillment Decisions on the Fly in and Online Retail Environment," (with J. Acimovic), *Manufacturing & Service Operations Management*, Winter 2015, Vol. 17, No. 1, pp 34-51.

78. “Setting Optimal Production Lot Sizes and Planned Lead Times in a Job Shop System,” (with Rong Yuan), *International Journal of Production Research*, (2016), Vol. 54, Issue 20, pp 6105 - 6120. DOI: 10.1080/00207543.2015.1073859.

79. "OM Forum - Practice-Based Research in Operations Management: What It Is, Why Do It, Related Challenges, and How to Overcome Them," (with Jeremie Gallien and Alan Scheller-Wolf) *Manufacturing & Service Operations Management*, Winter 2016, Vol. 18, No. 1, pp 5 - 14. http://dx.doi.org/10.1287/msom.2015.0566

80. "Strategic safety stock placement in supply chains with capacity constraints," (with Tor Schoenmeyr) *Manufacturing & Service Operations Management*, Summer 2016, Vol. 18, No. 3, pp 445 - 460. http://dx.doi.org/10.1287/msom.2016.0577.

81. "Inventory Management in a Consumer Electronics Closed-Loop Supply Chain," (with Andre Calmon), INSEAD Working Paper No. 2016/39/TOM , June 2016. Available at SSRN:https://ssrn.com/abstract=2622405 or http://dx.doi.org/10.2139/ssrn.2622405. To appear in *Manufacturing & Service Operations Management.*

82. "Scheduling rules to achieve lead-time targets in outpatient appointment systems," (with Thu Ba T. Nguyen, Appa Iyer Sivakumar), to appear in *Health Care Management Science* (2016), http://dx.doi.org/10.1007/s10729-016-9374-2.

83. "No Magic Bullet: A theory-based meta-analysis of Markov transition probabilities in studies of service systems for persons with serious mental illness," (with H. Stephen Leff, Clifton Chow) to appear in *Psychiatric Services* (2016), http://dx.doi.org/10.1176/appi.ps.201500523.

84. "Mitigating Spillover in Online Retailing via Replenishment," (with J. Acimovic), April 2014, revised September 2016, 40 pp. Available at SSRN: https://ssrn.com/abstract=2459097 or http://dx.doi.org/10.2139/ssrn.2459097. To appear in *Manufacturing & Service Operations Management.*

Proceedings

1. "A Mathematical Programming Procedure for Equipment Selection and System Evaluation in Programmable Assembly," (with D.E. Whitney), *Proceedings of the 18th IEEE Conference on Decision and Control*, Fort Lauderdale, Florida, December 1979 (invited paper, not refereed), 531-536.

2. "Extensions to a Tactical Planning Model for a Job Shop," *Proceedings of the 27th IEEE Conference on Decision and Control*, Austin, Texas, December 1988, pp. 1850-1855.

3. "Using Simulated Annealing to Select Least-Cost Assembly Sequences," (with J. M. Milner and D. E. Whitney), *Proceedings of IEEE Conference on Robotics and Automation*, May 1994.

4. "Spatial Yield Modeling for Semiconductor Wafers," (with A. I. Mirza, G. O' Donoghue, and A. W. Drake), *Proceedings of IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, November 1995

5. "Strategic Safety Stock Placement in Supply Chains," (with S. Willems) *Proceedings of the 1996 MSOM Conference*, Dartmouth College, Hanover NH, June 1996, pp. 299 - 304.

6. “Optimizing Monsanto’s Supply Chain under Uncertain Demand,” (with C. Gutierrez, M. Pulwer, H. Sidhu and G. Weihs), *Annual Conference Proceedings - Council of Logistics Management*, Orlando FL, October 1996, pp. 501-516.

7. “Optimizing the Supply-Chain Configuration for New Products,” (with S. P. Willems), *Proceedings of the 2000 MSOM Conference*, Ann Arbor, MI, 2000, 8 pp.

8. "Tactical Shipping and Scheduling at Polaroid with Dual Lead-Times," (with Kermit Threatte), *Proceedings of the 2002 SMA Conference*, Singapore, 2002, 8 pp.

9. "A Base Stock Inventory Model for a Remanufacturable Product," *Proceedings of the 2003 SMA Conference*, Singapore, 2003, 7 pp.

10. "Optimizing Safety Stock Placement in General Network Supply Chains," (with K. Lesnaia), *Proceedings of the 2004 SMA Conference*, Singapore, 2004, 7 pp.

11. "Traditional Inventory Models in an E-Retailing Setting: A Two-Stage Serial System with Space Constraints," (with R. Allgor and P. Xu), *Proceedings of 2004 SMA Conference*, Singapore, 2004, 6 pp.

12. "Logistics Network Design with Differentiated Delivery Lead-Time: Benefits and Insights," (with M.L.F. Cheong, and R. Bhatnagar), *Proceedings of 2005 SMA Conference*, Singapore, 20 pp.

13. "An Extension to the Tactical Planning Model for a Job Shop: Continuous-Time Control, " (with C. C. Teo, and R. Bhatnagar), *Proceedings of 2005 SMA Conference*, Singapore, 8 pp.

14. "The Complexity of Safety Stock Placement in General-Network Supply Chains," (with K. Lesnaia, and I. Vasilescu), *Proceedings of the 2005 SMA Conference*, Singapore, 5 pp.

15. "The Benefits of Re-Evaluating Real Time Fulfillment Decisions," (with P. Xu and R. Allgor), *Proceedings of 2005 SMA Conference*, Singapore, 7 pp.

16. “Performance Analysis of Order Fulfillment for Low Demand Items in E-tailing,” (with P. Chhaochhria), *Proceedings of 2007 SMA Conference*, Singapore, 5 pp.

17. “Capacity Planning in a General Supply Chain with Multiple Contract Types,” (with X. Huang), *Proceedings of 2007 SMA Conference*, Singapore, 6 pp.

18. "Reusing Personal Computer Devices – Good or Bad for the Environment?," (with S. Sahni, A. Boustani and T. Gutowski) IEEE/International Symposium on Sustainable Systems and Technology, Washington D.C, 2010

19. "Appliance Remanufacturing and Life Cycle Energy and Economic Savings,". (with S. Sahni, A. Boustani and T. Gutowski) IEEE/International Symposium on Sustainable Systems and Technology, Washington D.C, 2010.

20. "Water Desalination Supply Chain Modeling and Optimization" (with Malak T. Al-Nory), Data Engineering Workshops (ICDEW), 2013 IEEE 29th International Conference, April 2013.

Working Papers and Technical Reports

W1. "The Travelling Salesman Problem and Related Problems," (with B. Gavish), Operations Research Center, M.I.T., Working Paper No. 078-78, July 1978, revised and retitled, March 1981.

W2. "A Research Agenda for Models to Plan and Schedule Manufacturing Systems," (with C. Abraham, B. Dietrich, W. Maxwell, and C. Yano), Sloan School of Management, M.I.T., Working Paper No. 1689-85, revised July 1985.

W3. "Principles on the Benefits of Manufacturing Process Flexibility," (with W. C. Jordan), Sloan School of Management, M.I.T. Working Paper No. 3296-91-MSA, May 1991 (GM Research Laboratories Research Publication GMR-7310).

W4. "An Analytic Approach for Demonstrating the Benefits of Limited Flexibility," (with W. C. Jordan), Sloan School of Management, M.I.T. Working Paper No. 3297-91-MSA, May 1991 (GM Research Laboratories Research Publication GMR-7341).

W5. "Creating an Inventory Hedge for Markov-Modulated Poisson Demand: Application and Model," (with H. S. Abhyankar) , January 2000, long version. (short version published in M&SOM; see publications).

W6. "Optimizing Strategic Safety Stock Placement in Supply Chains," (with S. Willems), August 1998, long version. (short version published in M&SOM; see publications).

W7. "Strategic Inventory Placement in Supply Chains: Nonstationary Demand," (with S. Willems), August 2002 working paper (substantially revised version published in M&SOM, see publications).

W8. "A Constant-Inventory Tactical Planning Model for a Job Shop," (with J. S. Hollywood), working paper, January 2001, revised March 2004, January 2006, 36 pp.

W9. "A Dual-Channel Vendor-Buyer System with Minimum Purchase Commitment," with (Y. Wang and R. Bhatnagar), working paper, June 2008, 33 pp.

W10. "Capacity Planning in a General Supply Chain with Multiple Contract Types – Single Period Model," (with Xin Huang), June 2008, revised September 2008, 41 pp

W11. "Velocity-based Storage Assignment in Semi-automated Storage Systems," (with Rong Yuan and Tolga Cezik), July 2016, 32 pp. Available at SSRN: https://ssrn.com/abstract=2889354.

W12. "Performance Evaluation of Material Separation in a Material Recovery Facility using a Network Flow Model," (with Karine Ip, Mariapaola Testa, Anne Raymond and Timothy Gutowski), December 2016, 10 pp.

Teaching Cases

1. Steel Works, Inc, prepared by David Kletter, 1996

2. Meditech Surgical, prepared by Bryan Gilpin, 1995.

3. Apollo Paper Company, prepared by Charles DeWitt, 1995.

4. Use of a Queuing Model to Design a Lean System, prepared by Jamie Flinchbaugh, 2002

5. The Challenge at Instron, prepared by Dan Wheeler, 2000.

6. H. C. Starck, Inc., prepared by Thomas J. Carroll, 2000.

7. Ford Pan-European Durable Containers, prepared by Carmelo Anthony Palumbo, 2002.

8. Reebok NFL Replica Jerseys: A Case for Postponement, prepared by John C. W. Parsons, 2005.

9. American Axle and Manufacturing: Determining the Optimal Number of Bar Lengths for Axle Shaft Production, prepared by Heath Holtz, 2005.

10. Production Planning for Chemical Manufacturing, prepared by Shardul Phadnis, 2007.

Invited Presentations (Partial List):

1. "Improved Scheduling for Automatic Warehousing Systems: Simulation Tests," (with W.H. Hausman and L.B. Schwarz), Joint ORSA/TIMS National Meeting, New York, New York, May 1978.

2. "Logistic Failure vs. Mission Failure in Reliability Specifications," (with J. Keilson), Department of Defense Acquisition Research Symposium, Hershey, Pennsylvania, June 1978.

3. "A Methodology for Studying the Dynamics of Extended Logistics Systems," (with J. Keilson), Conference on Multi-Echelon Inventory Systems, George Washington University, November 1978.

4. "Multistage Lot-Sizing: An Iterative Procedure," Joint ORSA/TIMS Meeting, New Orleans, May 1979 (Also Purdue, April 1979).

5. "The Introduction of Feedback into a Hierarchical Production Planning System," TIMS XXIV International Meeting, Honolulu, June 1979.

6. "Production Scheduling: Theory and Practice," TIMS XXIV International Meeting, Honolulu, June 1979.

7. "System Balance for Extended Logistics Systems," (with J. Keilson), Conference on Multi-Echelon Inventory Systems, Philadelphia, Pennsylvania, November 1979.

8. "Base Stock Systems for Multistage Planning," Conference on Multi-Echelon Inventory Systems, Chapel Hill, North Carolina, June 1980.

9. "Optimization-Based Approaches to Vehicle Routing Problems," (with T.L. Magnanti), Joint ORSA/TIMS National Meeting, Colorado Springs, Colorado, November 1980.

10. "A Mathematical Programming Heuristic for Manufacturing System Design and Evaluation," (with B.W. Lamar) CORS/TIMS/ORSA National Meeting, Toronto, May 1981.

11. "The Dynamics of a Multiechelon Inventory System for a Repairable Item," (with J. Keilson), ORSA/TIMS National Meeting, Houston, October 1981.

12. "A Study of Production Smoothing in a Job Shop," (with A.B. Cruickshanks and R.D. Drescher), TIMS/ORSA National Meeting, Detroit, April 1982.

13. "Scheduling of Re-entrant Flow Shops," (with H.C. Meal, D. Stefek, A.H. Zeghmi), TIMS/ORSA National Meeting, Chicago, May 1983.

14. "An LP Planning Model for a Mental Health Community Support System," (with M. Dada and H.S. Leff), ORSA/TIMS National Meeting, Orlando, November 1983.

15. "Operational Analysis of a Job Shop," TIMS/ORSA National Meeting, San Francisco, May 1984.

16. "Two-Stage Production Planning in a Dynamic Environment," (with H.C. Meal), ORSA/TIMS National Meeting, Dallas, November 1984.

17. "Determining the Spares and Staffing Levels for a Repair Depot," TIMS/ORSA National Meeting, Boston, May 1985.

18. "Developing and Use of a Production Flow Plan," ORSA/TIMS National Meeting, Atlanta, November 1985.

19. "Safety Stocks in Manufacturing Systems," ORSA/TIMS National Meeting, Miami, October 1986.

20. "Equipment Selection and Task Assignment for Multiproduct Assembly System Design," (with C.A. Holmes), ORSA/TIMS National Meeting, St. Louis, October 1987.

21. "A Multiechelon Inventory Model for Fixed Reorder Intervals," TIMS/ORSA National Meeting, Washington, DC, April 1988.

22. "Production Planning in a Dynamic Environment," ORSA/TIMS National Meeting, Denver, October 1988. (Also, Yale, November 1988, Carnegie-Mellon, April 1989.)

23. "Cyclic Schedules in Stochastic Environments," CORS/TIMS/ORSA National Meeting, Vancouver, Canada, May 1989.

24. "Production Planning over a Multiplant Operation," ORSA/TIMS National Meeting, Philadelphia, October 1990.

25. "Principles on the Benefits of Manufacturing Flexibility," (with W. C. Jordan), TIMS/ORSA National Meeting, Nashville, May 1991. (Also, University of Minnesota, February 1991, Ohio State, November 1991).

26. "Some Thoughts on Inventory Modeling and Diagnostics," UCLA Conference in Honor of El Buffa, Los Angeles, November 1991.

27. "Reducing Flow Time in Aircraft Manufacturing," (with Jackson Chao), ORSA/TIMS National Meeting, San Francisco, October 1992.

Thesis Supervision (Partial List):

R. Blake, "Allocation of Items Under Fixed Capacity," S.M., June 1978 (reader).

M. Pendrock, "A Hierarchical Approach to Integrated Production and Distribution Planning," S.M. June 1978 (reader).

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